Spatial Orientation and Directional Judgments in Pilots vs. Nonpilots

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BACKGROUND: Reading a map requires the ability to judge one's position in a large-scale space from information presented in a small-scale representation. Individuals are more accurate and faster in making judgments when the "up" direction on the map is the same as the "forward" direction of the environment, which is when a map is aligned with the perspective of the spatial layout they have learned (alignment effect). The aim of this study was to explore whether military pilots, who have high spatial abilities, would not show the alignment effect compared with nonpilots.

METHODS: Recruited were 20 military pilots and 20 nonpilots. Mean flight hours were 418.75. Nonpilots without flight experience were matched for age and education with pilots. Subjects were asked to learn a map and to perform directional judgments to verify whether the alignment effect was present considering absolute angular errors.

RESULTS: An ANOVA for mixed designs on absolute angular errors revealed a main "group" effect: pilots performed better than nonpilots (pilots: $M = 22.60 \pm 5.57$; nonpilots: $M = 82.59 \pm 5.56$). A main "directional judgments" effect was also observed: aligned judgements were easier than contra-aligned judgements (aligned, $M = 9.277 \pm 0.938$; contra-aligned, $M = 11.004 \pm 0.805$). ANOVA showed a significant "group $\times$ directional judgments" interaction: post hoc comparison showed that contra-aligned were more difficult than aligned judgments for nonpilots.

DISCUSSION: High visuo-spatial abilities preserved pilots from having alignment effect bias. They performed directional judgments equally well, being less influenced by the increased cognitive effort requested by the changing perspective.

KEYWORDS: directional judgements, spatial orientation, navigational skills, pilots, flight safety.

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Situation awareness (SA) is a well-known concept in the flight environment. It refers to multiple tasks that must be time shared in a dynamic environment, often with severe temporal constraint.[18] It is an extremely mutable situation, where the picture itself continuously changes because very long distances are covered in a very short time. SA relates to activities continually performed by pilots to gain awareness of potential hazards in the external world. To perform surveillance activities, the pilot needs have high awareness in four specific areas: environmental, spatial, temporal, and navigational. To achieve environmental awareness a pilot must have information on the weather, the airport conditions, and the presence of other aircraft. Spatial awareness requires, for example, cognition of altitudes, flight trajectory, and speed.[6,16] Temporal awareness represents the pilot's knowledge of events while the mission evolves. Navigational awareness, according to Aretz,[1] is the pilot ability to answer the following question: "Am I where I should be in the world?" This question includes the two main spatial reference systems essential for orientation: egocentric and allocentric. A frame of reference, in fact, can be based on one's position in relation to the spatial surroundings (egocentric) or it can be centered on one object or its parts with respect to other objects present in the environment

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(allocentric) (e.g., Paillard).[11] In other words, the location of one object is defined relative to the location of other objects. In this way, the previous question can be rephrased as "Am I—egocentric reference—where I should be in the world—allocentric reference?" However, maintaining orientation during flight requires rotating in three dimensions, faster and with higher workload than spatial orientation in ground navigation. Generally speaking, navigational awareness is reached by using triangulation, which establishes the geometries between egocentric and allocentric systems. These processes are mental rotation that aligns egocentric and allocentric systems; image comparison that confirms the alignment between egocentric and allocentric systems; and translation that monitors the position of the egocentric system as it proceeds through the allocentric system.[1]

Reading a map requires the ability to make judgments about one's position in a large-scale space from information presented in a small-scale representation.[3] Generally, individuals are more accurate and faster in making judgments when the "up" direction on the map is the same as the "forward" direction in the environment, i.e., when a map is aligned with the perspective of the spatial layout they have learned (alignment effect).[8,10] In detail, the alignment effect occurs when an individual has to mentally recall an environment previously learned with a different perspective.[2] In fact, when the perspectives do not correspond, there is a cost to speed (we take more time) and accuracy (we make more mistakes, for example taking the wrong way or the longest one).[18,25] Individual differences should also be considered in order to explain the alignment effect. Nori et al.[9,10] showed that this depends on spatial cognitive style, representing the way in which environmental cues are processed. Pazzaglia and De Beni[13] demonstrated that people skilled in mental rotation ability, after a four-trial training, were free from the alignment effect. Very recently, Piccardi et al.[14] found that in order to be accurate in changing perspective, skill in mental rotation is not enough; one also needs to be skilled in inspecting the mental environmental representation. Both inspection and mental rotation are components of mental imagery, a cognitive process that arises when perceptual information is accessed from memory, originating the experience of "seeing with the mind's eye."[7]

Pilots must be able to constantly provide correct directional judgements even when visual cues are not available. For achieving this goal, a high-level of mental imagery is required and, in particular, pilots have to be able to perform fast and accurate mental rotations. Verde et al.[24] demonstrated that pilots are significantly better in mental rotation compared to the general population.

In the present study, considering that pilots are skilled in mental rotation, have a higher spatial cognitive style, and passed a selection to enter the Air Force Academy, we hypothesized that they would be free from the alignment effect without any kind of training. Specifically, we expected they would be equally accurate in performing aligned and contra-aligned judgments and would take the same time for both judgments.

METHODS

Subjects

We investigated 20 male military pilots and 20 male nonpilots: 10 pilots were expert jet-pilots and 10 were junior pilots at the end of jet training. Mean flight hours were 418.75 (SD = 377.51). Nonpilots were college students coming from different scientific disciplines (i.e., engineering; economics; psychology; medicine) with no flight experience. They were matched with the pilots for age [$F(1,38) = 3.708$, $P = 0.06$; Pilots: M = 28.05 yr, SD = 2.04 yr; Nonpilots: M = 30.05 yr, SD = 4.17 yr] and education level [$F(1,38) = 0.58$, $P = 0.45$; Pilots: M = 18.00 yr, SD = 0.00 yr; Nonpilots: M = 17.50 yr, SD = 2.98 yr]. In the pilots group there was an ambidextrous and one left-handed subject, whereas in the nonpilots group subjects were all right-handed.[17] None of the subjects had history of neurological or psychiatric illness. No subjects showed deficits in performing the Thurstone's Primary Mental Ability Test Cards[12] (Response Time: Pilots M = 178.3 ± 61.2 s; Nonpilots: M = 380.7 ± 139.2 s; Accuracy: Pilots: 15.7 ± 1.6; Nonpilots: M = 15.7 ± 1.9).

The study protocol, which was in accordance with the ethical principles of the Declaration of Helsinki, was approved by the local ethics committee (Department of Psychology, University of Bologna, Italy). All subjects gave their written informed consent before taking part in the experimental testing.

Materials

Seven paths were adopted from those used by Levine et al.[8] to test the alignment effect. This task analyses the ability to correctly read a map and to mentally rotate it: Levine et al.[8] have demonstrated that the orientation of the map during learning will be important afterwards when the person will extract information from the map in order to imagine a different perspective of the learned map. This happens when the subject has to provide a contra-aligned judgement (the recall perspective is rotated by 180°), has to update his/her point of view, and has to rotate it 180°. Furthermore, when the imagined perspective (aligned judgement) is the same of the learned perspective, his/her judgement is more accurate and faster.

Two of the paths were only used for training purposes. Each path was constructed with four points and three segments of varying lengths. The two turns consisted of angles that were either 110° and 70°, or 90° and 90° (see **Fig. 1**). Each path was printed on a sheet of paper (21 cm × 29.7 cm) and the length of the three segments of each path varied from 3.5 cm to 17 cm.[9] We assigned a number from 1 to 4 to each corner of the path, starting at one corner and proceeding sequentially through the path.[15]

The five paths used for the experiment were randomized and then the same order was used for all subjects.[9,10] For each path, 2 judgments of direction were made by subjects, 1 aligned and 1 contra-aligned, for a total of 10 judgment direction tasks (5 aligned and 5 contra-aligned). The order of these judgments was determined randomly for each path with the restriction that half of the layouts had aligned judgments before contra-aligned and the other way round for the other half. The same order was used for all subjects.

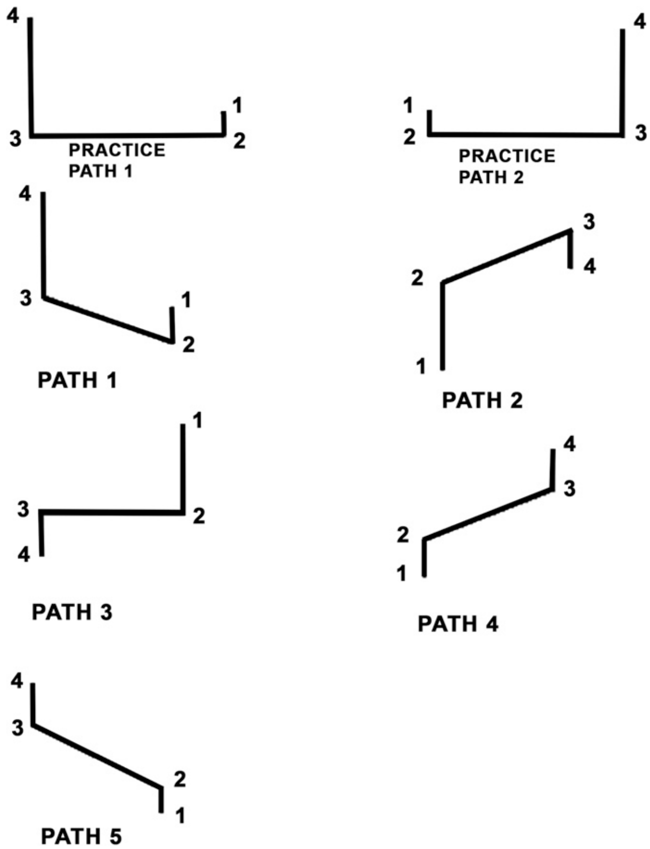

Fig. 1. The picture depicts the five paths. Each path was constructed with four points and three segments of varying lengths. The two turns consisted of angles that were either 110° and 70°, or 90° and 90°.

The correct response for aligned and contra-aligned judgments could be either in front of or behind the subjects. Correct responses ranged from 45° to 315°. In order to give their directional judgments, subjects used a cardboard dial with a diameter of 30 cm, similar to the one used by Nori et al.[10] Attached to the center of the circular dial was a pointer that could be rotated by 360°. The dial was marked every 5° (0° to 355°, clockwise) so that the experimenter could record the subjects' responses. There were marks on the outer edge of the dial at 0°, 90°, 180°, and 270° to help the subjects keep the direction in mind. The notch at 0° was larger in order to enable subjects to keep 0° in forward position. A hand-held stopwatch was used to record the response time.

Procedure

Each subject was individually tested. Subjects were told that they would learn a series of four-point paths and they would be asked to make two directional judgment tasks. Subjects were given detailed instructions regarding the circular cardboard dial. Each subject was then asked to learn five paths by looking at each path for 30 s in order to learn the positions of the numbers.

Successively, the experimenter would remove the path and put the circular cardboard dial in front of the subjects in order to let them carry out the directional judgment tasks. Subjects carried out two directional judgment tasks on each path: they were told to imagine themselves at a specific point on the path, to look at another point, and to point to a target location on the path using the circular dial. One of the directional judgment tasks was aligned (where the imagined perspective was the same as the learned one) and the other one was contra-aligned (where the imagined perspective was rotated by 180° from the learned one) in order to identify the presence or absence of the alignment effect. The experimenter started the hand-held stopwatch immediately after the target location was announced and stopped the stopwatch when the subjects removed their hands from the dial. After completing one trial, the procedure was repeated for the next path. The experimenter recorded the response time in seconds and the angular direction in degrees (read from the dial). This gave the response time and absolute angular errors as dependent variables, calculated as the difference in degrees between the exact position and the position marked by the subjects.

Statistical Analysis

A three-way analysis of variance with mixed designs was carried out with 2 levels of "group" (pilots vs. nonpilots), 2 levels of "directional judgment tasks" (aligned vs. contra-aligned), and 5 levels of "path" repeated factors. We analyzed both absolute angular errors and response time.

RESULTS

Absolute Angular Errors

The main group effect (pilots vs. nonpilots) was statistically significant [$F(1,38) = 57.90$, $P < 0.0001$, partial $\eta^2 = 0.604$]. The means for the absolute angular errors were as follows: pilots, M = 22.60°, SD = 5.57°; nonpilots, M = 82.59°, SD = 5.56°. The main directional judgment tasks effect (aligned vs. contra-aligned) was statistically significant [$F(1,38) = 55.33$, $P < 0.0001$, partial $\eta^2 = 0.59$]. The means for the absolute angular errors were as follows: aligned, M = 23.59°, SD =2.85°; counter-aligned, M = 81.60°, SD = 7.31°. The main path effect was not statistically significant [$F(4, 35) = 2.24$, $P = 0.08$, partial $\eta^2 = 0.20$]. We also found that the interaction "group × directional judgment tasks" was statistically significant [$F(1,38) = 30.42$, $P < 0.0001$, partial $\eta^2 = 0.45$]. Post hoc comparison with Bonferroni correction showed that contra-aligned judgements were more difficult than aligned judgments for the nonpilot group ($P < 0.0001$), whereas in the pilots' group there was no difference: aligned and contra-aligned judgments had the same difficulty ($P = 0.18$). Moreover, both in aligned ($P = 0.005$) and contra-aligned judgments ($P < 0.0001$), nonpilots (respectively, aligned: M = 32.07° ± 4.03°; contra-aligned: M = 133.10° ± 10.33°) made greater magnitude mistakes than pilots (respectively aligned: M = 15.10° ± 4.03°; contra-aligned: M = 30.10° ± 10.33°). No other reliable main effects or interactions were found in our analysis.

In order to show whether the flight hours of military pilots predict the performance on aligned and contra-aligned judgments, we performed two different regression analyses considering as independent variable the flight hours and as dependent variable the mean of absolute angular errors of the five paths. The analysis considering both aligned and contra-aligned judgments was not statistically significant, respectively: aligned [$F(1, 19) = 0.52$, $P = 0.48$, $r^2 = 0.02$], contra-aligned [$F(1, 19) = 0.07$, $P = 0.79$, $r^2 = 0.004$].

Response Time

The main group effect (pilots vs. nonpilots) was statistically significant [$F(1, 38) = 7.41$, $P = 0.01$, partial $\eta^2 = 0.16$]: pilots ($M = 12.28 \pm 1.111$ s) took longer than nonpilots ($M = 8.00 \pm 1.11$ s) in both types of directional judgements. The main directional judgment tasks effect (aligned vs. contra-aligned) was statistically significant [$F(1, 38) = 5.09$, $P = 0.03$, partial $\eta^2 = 0.118$]. Alignment judgments were faster than the contra-aligned judgments. The means for the response time of the two judgments were as follows: aligned, $M = 9.28 \pm 0.94$ s; contra-aligned, $M = 11.00 \pm 0.81$ s.

The main path effect was also statistically significant [$F(4,35) = 4.51$, $P = 0.005$, partial $\eta^2 = 0.34$). Post hoc comparison with Bonferroni correction showed that performing directional judgments in path number 3 was faster ($M = 8.19 \pm 0.79$ s) than in path number 4 ($P = 0.007$, $M = 11.75 \pm 1.24$ s) and number 5 ($P = 0.04$, $M = 10.56 \pm 0.94$ s).

Moreover, we found a group × directional judgment tasks significant interaction [$F(1,38) = 13.83$, $P = 0.001$, partial $\eta^2 = 0.267$]. Bonferroni post hoc comparison showed that nonpilots ($M = 10.287 \pm 1.139$ s) took more time to give contra-aligned than aligned directional judgments ($M = 5.75 \pm 1.326$ s; $P < 0.0001$), whereas pilots took the same time ($P = 0.31$; aligned: $M = 12.84 \pm 1.326$ s; contra-aligned: $M = 11.72 \pm 1.14$ s). Moreover, nonpilots were faster than pilots ($P = 0.001$) in performing aligned directional judgments, whereas there was no significant difference in performing contra-aligned directional judgments ($P = 0.38$).

Path × directional judgment tasks interaction was also statistically significant [$F(4,35) = 9.12$, $P < 0.0001$, $\eta^2 = 0.51$]. Bonferroni post hoc interaction showed that subjects took more time to perform contra-aligned ($M = 12.92$, $SD = 1.29$ s) than aligned ($M = 6.82$, $SD = 0.75$ s) directional judgments in path number 1 ($P < 0.0001$) and number 2 (contra-aligned: $M = 13.38$, $SD = 1.35$ s; aligned: $M = 7.31$, $SD = 1.02$ s; $P < 0.0001$). Moreover, aligned directional judgments in path number 4 ($M = 11.74$, $SD = 1.81$ s) and 5 ($M = 12.03$, $SD = 1.39$ s) took longer than in path number 1 (respectively, $P = 0.024$ and $P = 0.003$). As for contra-aligned directional judgments, subjects took longer to perform path number 1 than number 3 ($M = 7.79$, $SD = 0.80$ s; $P = 0.006$) and number 5 ($M = 9.08$, $SD = 1.03$ s; $P = 0.012$); likewise, path number 2 took longer than path number 3 ($P = 0.002$) and number 5 ($P = 0.049$).

We performed two different regression analyses considering as independent variable the flight hours and as dependent variable the mean of response time of the five paths. The analysis considering both aligned and contra-aligned judgments was not statistically significant, respectively: aligned [$F(1, 19) = 0.11$, $P = 0.74$, $r^2 = 0.006$] and contra-aligned [$F(1, 19) = 0.46$, $P = 0.50$, $r^2 = 0.02$].

Finally, results indicated a significant group × directional judgments × path interaction [$F(4,35) = 5.26$, $P = 0.002$, $\eta^2 = 0.375$]. Bonferroni post hoc interaction showed that nonpilots were faster than pilots in performing aligned directional judgments in all paths (P = from 0.047 to 0.001), as well as in contra-aligned judgements, but only in path number 1 ($P = 0.03$) and number 2 ($P = 0.04$). Moreover, the nonpilots group was faster in performing contra-aligned directional judgments in path number 3 than number 4 ($P = 0.05$). Pilots were faster in performing aligned directional judgments in path number 1 than in number 3 ($P = 0.03$), number 4 ($P = 0.001$), and number 5 ($P = 0.001$); moreover, they were also faster in path number 2 ($P = 0.02$) and 3 ($P = 0.04$) than in path number 5. In performing contra-aligned directional judgments, pilots took more time in path number 1 than in path number 3 ($P = 0.001$), number 4 ($P = 0.04$), and number 5 ($P = 0.01$); they also took more time in path number 2 than in path number 3 ($P = 0.01$) and number 5 ($P = 0.010$). The nonpilots group was slower in performing contra-aligned directional judgments than in performing aligned directional judgments in path number 1 ($P = 0.02$), 2 ($P = 0.01$), and 4 ($P = 0.02$). Pilots performed aligned directional judgments faster than contra-aligned directional judgments in path number 1 ($P = 0.001$) and 2 ($P = 0.01$), whereas they performed contra-aligned directional judgment faster than aligned ones in path number 3 ($P = 0.017$), 4 ($P = 0.015$), and 5 ($P = 0.000$). Means and standard deviations are shown in **Fig. 2**. Statistical analysis did not show any other significant results.

DISCUSSION

In the present study we compared the ability to perform directional judgements after studying a map that could be aligned (the learned perspective is the same that the recall perspective) or contra-aligned (the recall perspective is rotated by 180°) between pilots and nonpilots. Our hypothesis was that pilots were more accurate and faster than the civilian population and they would not show the alignment effect. We assumed this hypothesis taking into consideration that pilots had higher visuo-spatial abilities than nonpilots.[22–24] In particular, Verde et al.[24] found that pilots are better at performing mental rotation, a crucial skill in reducing the alignment effect, than the general population.[13,15] Indeed, also in the present study, pilots were faster than nonpilots on Thurstone's Primary Mental Ability Test Cards and both groups were accurate at this test, as mentioned in the sample description. Neuroscientific data show an overlap between areas involved during mental rotation tasks and airplane altitude judgment tasks, i.e., an emulation of pilots' real-life scenarios.[20] However, the same authors also found that "there are also significant differences in activation patterns between instrument interpretation and non-aviation based mental rotation. … our results indicate that abstract mental rotation skills might not be a reliable predictor for actual

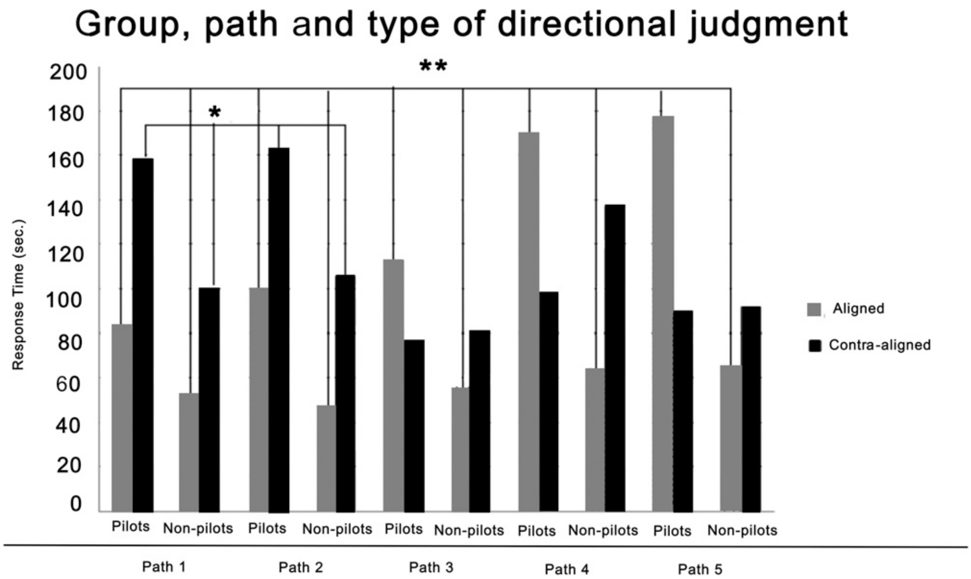

Fig. 2. In the graph are reported means (standard deviations) considering group, path, and type of directional judgments. Asterisks indicate statistically significant differences.

that pilots have a larger working memory capability that is crucial in performing spatial orientation tasks.[23,26]

Indeed, the different performance of pilots and nonpilots could be interpreted considering task cognitive demands:[4] a perspective changing task, i.e., contra-aligned judgments, required high cognitive demands in representing and transforming mental representation previously acquired from a different point of view. The cognitive load, in fact, increases depending on the number of interacting elements to be simultaneously maintained in working memory. Consequently, differences could arise in spatial orientation tasks that require a consistent load of visuo-spatial working memory. These span differences are particularly marked in active tasks, where subjects are required to elaborate, integrate, and transform the visual imagined material.

In the general population, low performance in mental rotation tasks produce more errors in pointing tasks in the contra-aligned condition compared to different orientations or the aligned condition.[13] This is could be considered as a generic spatial bias which involves everyone. Nevertheless, Piccardi et al.[14] found that even other mental imagery components, like generation, have a role when individuals have to provide directional judgments maintaining the same orientation of the learned map. Conversely, visual mental inspection has a role when individuals have to provide directional judgments with different orientation (in directional judgments both with different orientation and in contra-aligned orientation). The ability to transform a mental image plays an important role when individuals have to produce contra-aligned directional judgments, highlighting mental transformation component contributions when the task has a higher cognitive load.

Interestingly, we found that nonpilots were faster than pilots in performing aligned judgements, but there were no differences in contra-aligned. However, time differences were not predictive of accuracy. In fact, nonpilots were faster, but produced significantly more errors. Moreover, in nonpilots, aligned and contra-aligned judgements required different time, with contra-aligned being more difficult. Conversely, in pilots, the time spent on the two different judgments was the same and accuracy in contra-aligned judgments was enormously higher than in nonpilots. A possible interpretation could be a cognitive time cost which promotes accuracy.

Alternatively, it seems that pilots follow a spatial strategy to approach visuo-spatial information regardless of the task difficulty. As an example, all our pilots were trained in

real-life spatio-motor skills of pilots and likely other trained professionals."[20, p.5] These results partially support that flight-related activities and typical spatial tasks are comparable and that one ability could affect the other.

Pilots often face situations in which perspective is rotated, e.g., approach to landing, where they have to reach and maintain the correct glide path and plan above the runway. This activity requires a quick encoding of all useful environmental and instrumental information in order to evaluate, as soon as possible, the amount of deviation from the glide path and from the runway positions.[5,20]

In addition, Sutton et al.[20] reported that undergraduate student pilots were more accurate at estimating directions between landmarks in a virtual town than matched nonpilot controls. However, they did not find that undergraduate student pilots were better at perspective taking and/or pointing per se, interpreting this result as related to previous flight experience. The authors interpreted these data as suggesting that flight experience may affect the formation and retrieval of a cognitive map representation by way of improved perspective taking. In our case, pilots performed better than nonpilots in directional judgements in terms of accuracy likely due to several factors. From one perspective, a greater flight experience that led to higher familiarity with the 3-dimensional navigation system could have improved their ability in performing spatial tasks. However, in our case, statistics did not show that flight hours predict performance. From another perspective, pilots entering the Italian Air Force Academy have to pass a selection process involving a multistage process with several pass/fail steps. To measure intellectual efficiency, several batteries of standardized tests (e.g., PILAPT's battery; VIENNA test) are administered to candidates for assessing cognitive ability. This type of selection process is aimed at targeting the higher visuo-spatial performers.[14,23] We can assume that the strict selection process may be partially responsible for this result. Furthermore, it is known the use of "bullseye" or "bull," as commonly referred to by fighter pilots.

The bullseye is a predetermined location within the theater of operations that is programmed into every global positioning system (GPS system). Its location is always classified and is regularly changed. In practical terms, as it is explained in common videogames,[19] according to a common reference point known only to a group of pilots, it allows the location of the position or a target with respect to the bullseye. The position of the bullseye is highlighted on the map and track lines are drawn departing from the bullseye toward the exterior of the map, following a clock scheme where the first line going toward noon (i.e., 12:00) corresponds to magnetic North and so on, moving clockwise every 30° until 12 radial lines, all departing from the same bull, are reached. This kind of procedure could be applied to other locations on the map, facilitating the processing of visuo-spatial information. It appears that pilots adopted a spatial strategy based on the way to perform spatial tasks in order to obtain the best performance in terms of accuracy, despite being relatively slower.

In conclusion, pilots are free from the alignment effect, showing less sensitivity to spatial bias, analogously to what happens with topographical memory during environmental interference.[22] Military pilots are resistant to this negative spatial bias and are able to use an alternative strategy even if more difficult in terms of cognitive load and with a cost in terms of time compared to the nonpilot population.

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